

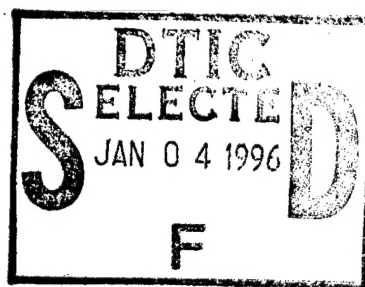
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PLASTIC MEDIA BLASTING



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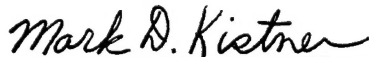
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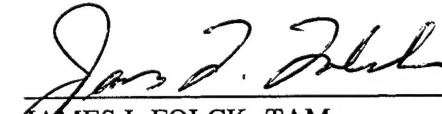
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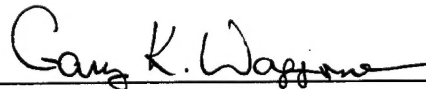
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## Foreword

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The majority of this report has been taken from a draft AFSC Design Handbook "Paint Stripping Technologies" prepared by Captain Gary Meuer and others. It is the intent of the Air Force to prepare Technical Reports for each of the new nonchemical paint stripping processes. This first report is devoted to the Plastic Media Blasting (PMB) process.

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## Executive Summary

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In the early 1980s, several aerospace organizations started to evaluate the use of plastic abrasives to remove surface coatings from component parts and airframes. Work by Avco in Nashville, Tennessee, centered around cleaning coatings from wing components, where the coating was removed down to the anodize finish. In 1981 the Navy requested proposals for alternative paint stripping methods, including abrasive blasting, dry ice, waterjets, and other processes deemed less hazardous than currently used chemical paint strippers. Later, Navy personnel at the Pensacola Naval Air Station, Florida, evaluated PMB as a means to depaint helicopters and components.

Around 1983 Air Force personnel from Hill AFB, Utah, initiated a Productivity-Reliability-Availability-Maintainability (PRAM), Project Number OO-143, program to validate a PMB blasting process acceptable for repainting the F-4 Phantom aircraft. Early tests at the engineering, metallurgical, and chemical laboratories at Hill AFB were so encouraging that the Air Force personnel predicted enormous savings in money and labor in favor of adopting the PMB process over current chemical stripping operations.

In 1985 a project to build the first PMB blast booth for airframes was approved. The Hill AFB engineers announced their intention to patent and license the PMB process for aircraft paint stripping. Apparently the PMB repainting process had been patented in 1947 by the du Pont Company, so the patent application was withdrawn. Nonetheless, PMB attracted great attention and imitation in the aircraft paint stripping industry. The commercial firm (U.S. Technology) that originally furnished Hill AFB with the detritus of polyester and melamine buttons, profited from being first in line and, sold large quantities of PMB to the Air Force, especially to Hill AFB. Other firms were quick to jump on the bandwagon, and soon there was competition and a pervasive and growing use of the PMB process for military and commercial paint stripping facilities.

The initial joy of replacing the hazardous chemical paint stripping methods with a more efficient and less expensive PMB system was short lived. Test results from various organizations indicated some potential drawbacks in undesirable materials effects. Furthermore, an early commercial PMB operator, using an untrained, semiskilled blasting crew, burned holes through portions of the aircraft skin. Similar problems appeared when blast operators gouged divots in composite materials while using poor blasting techniques and aggressive blasting parameters. Consequently, there was a

need for long-term, in-depth testing of the PMB process with development of suitable blasting parameters, blast equipment, and training programs.

Much of the PMB work has been done in concert with media manufacturers and blasting equipment suppliers. Sand blasting methods and equipment were modified to use this new "soft blast" process. Blast machines, media delivery systems, hoses, nozzles, protective clothing, and a reasonably cheap source of soft blasting media were developed as user experience and concerns became known.

The PMB process is not a panacea for all paint removal problems. Limitations on material type and thickness apply to aerospace hardware. To avoid media intrusion problems, the structure must be masked; thus all of the paint cannot be removed by blasting. The plastic media dust/paint chip waste stream may be considered a leachable and hazardous waste, depending on the constituents of the paint and primers being removed, which contaminate the waste media. The paint waste may require proper disposal methods as specified in the Environmental Protection Agency (EPA) and the Department of Transportation (DOT) regulations. If the waste media is found to be nonhazardous, it still presents a large waste volume to dispose of. With all of its faults, the PMB process still is the most effective nonchemical coating removal system currently in use, with the widest application at field- and depot-level commercial and military facilities.

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## **1.0 INTRODUCTION**

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### **1.1 Plastic Media Blasting (PMB)**

#### **1.1.1 Scope**

The intent of this report is to provide fundamental guidelines for engineers, facility designers, and production supervisors concerned with the removal of paint coatings from aerospace hardware. It does not provide a comprehensive accounting of all PMB effects and applications; rather it is to document PMB experience obtained at various research, test, and maintenance organizations during the last several years. A look at the maturing PMB technology to understand what media and process parameters the depainting community has tried and found acceptable will allow the future PMB facilities to learn and benefit from our past experience.

Experiences other than military aerostructures are presented to reflect the wide diversity of applications of abrasive blasting for cleaning and coating removal operations.

#### **1.1.2 Purpose**

This report is the first of a series which will cover the implementation and use of a nonchemical depainting process. The salient features of the plastic media blasting (PMB) process, the concerns with its use, and the associated effects are discussed. The purpose of this report is to provide sufficient useful data to enable engineers to outline requirements to implement a PMB depainting capability in their maintenance organizations.

## **1.2 Background**

Paint coatings are applied, maintained, removed, and replaced for a variety of reasons. The paint coatings may provide identification and marking, protection against corrosion, visual and electronic camouflage, thermal protection, erosion resistance, and decorative qualities. For fiberglass,

graphite, boron, Kevlar®, or other composite material systems, the paint coating also provides a barrier protecting the matrix resin material from degradation due to moisture, environmental conditions, and ultraviolet light effects.

Chemical paint removal technology has been relatively stable since the advent of nonflammable methylene chloride-based paint strippers. When zinc chromate (alkyd primers) and lacquer (acrylic nitrocellulose) or enamel (alkyd) topcoats were used, the methylene chloride strippers quickly and efficiently removed the coatings from metallic substrates. Unfortunately, the lacquer and enamel coatings are susceptible to degradation from abrasion, erosion, weathering, and incompatibility with aircraft fluids, lubricants, and fuels. The military service life expectancy of these older paint systems was only 1 or 2 years and required continual inspection, maintenance, and touch-up.

As coatings improved, they transitioned from lacquers and enamels to epoxies, polyurethanes, and fluoropolymers. The traditional methylene chloride-based paint strippers added activators, typically consisting of phenols, formic acid, or amines, to enhance removal. Environmental and safety hazards associated with chemical strippers created pressure to seek alternative, less expensive, less toxic, and nonhazardous waste-generating processes in the depainting industry.

Additionally, organic matrix composites, such as graphite/epoxy, boron/epoxy, and fiberglass, are now routinely incorporated into aircraft structure. These advanced composite surfaces are generally thought to be susceptible to degradation from chemical stripper absorbed into the matrix resin system, causing loss of mechanical properties. However, many composite parts are routinely stripped with chemicals applied for short durations and then mechanically scraped clean of paint and chemical residue before final hand sanding and repainting.

Methylene chloride-based paint strippers have been the standard since World War II. The strippers are very effective on enamels and lacquers. Newer formulations incorporating acids and caustics allow the tougher epoxy and polyurethane paint systems to be degraded. However, the environmental concerns have resulted in increasingly stringent regulations governing the use of chemicals known or expected to cause damage to the environment or ecology. These have taken the form of outright bans on certain chemicals in some locations, restrictions on volatile organic compound (VOC) content, restrictions on vapor pressure, restrictions on the weight of organic solvents that can be emitted to the atmosphere, restrictions on waste disposal, and similar measures. By 1997, EPA regulations will prohibit stripping of aircraft using chemical strippers which contain any of 189 listed hazardous air pollutants (HAPS) including methylene chloride.

Much attention has been focused on the protection of the health of workers and the local community to the hazards of chemical use. This has resulted in a greater awareness on the part of both affected groups to the chemicals to which they are exposed. The "duty to inform" that has been imposed on chemical companies by Occupational Safety and Health Agency (OSHA) and numerous community right-to-know measures has raised the consciousness of these groups, in particular with respect to known or suspected carcinogens.

Many of these concerns with regard to paint strippers have focused on methylene chloride. Probably the most far-reaching of these questions relate to the possible carcinogenicity of methylene chloride and to the disposal problems for waste containing very low levels of methylene chloride.

In 1986 methylene chloride was added to the National Toxic Products (NTP) list of chemicals that may reasonably be expected to cause cancer in humans. This addition to the NTP list was based on evidence that has been the subject of some debate as to its validity and relevance, but the fact of its presence on the list made it necessary to show, on material safety data sheets and labels for products containing methylene chloride, warnings that the product contained a suspected carcinogen. This caused concern resulting in companies restricting the use of these products to designated areas where vapor concentrations could be more readily controlled, providing greater ventilation in those areas where methylene chloride is handled, providing respiratory protective devices to workers, or some combination of these three.

Disposal of waste containing methylene chloride is increasingly difficult and expensive. Very small amounts of methylene chloride (70 parts per million) may contaminate very large amounts of rinse water to the extent that the water must be treated to remove the methylene chloride or it must be disposed of as hazardous waste. These regulations are already expensive to comply with, and they can only be expected to become more stringent and expensive in the future. The most suitable answer is to eliminate methylene chloride wherever possible and replace it with a less polluting alternative.

Environmentally acceptable products are being developed by chemical companies replacing chlorinated solvents, phosphate cleaners, and other hazardous chemicals with reformulated compounds containing no known carcinogens or listed HAPs. Alternative paint strippers incorporating solvents, N-methyl pyrrolidone, benzyl alcohol, dibasic esters, and others are in development. Paint softeners are being sought to be used in conjunction with soft blasting processes to increase removal efficiency while reducing total hazardous waste production.

PMB is an accepted alternative depainting method to chemical stripping. This process has been studied extensively since the early 1980s to evaluate coating removal effectiveness versus the negative

effects on material substrates. Plastic blasting media are ranked by hardness, density, and physical chemistry.

In the early 1980s, several aerospace organizations started to evaluate the use of plastic abrasives to remove surface coatings from component parts and airframes. Work by Avco in Nashville, Tennessee centered around cleaning coatings from wing components, where the coating was removed down to the anodize finish. In 1981, the Navy requested proposals for alternative paint stripping methods, including abrasive blasting, dry ice, waterjets, and other processes deemed less hazardous than currently used chemical paint strippers. Later, Navy personnel at the Pensacola Naval Air Station, Florida evaluated PMB as a means to depaint helicopters and components.

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Much of the PMB work has been done in concert with media manufacturers and blasting equipment suppliers. Sand blasting methods and equipment were modified to use this new "soft blast" process. Blast machines, media delivery systems, hoses, nozzles, protective clothing, and a reasonably cheap source of soft blasting media were developed in response to user experience and concerns.

### **1.3 State-of-the-Art**

The Air Force Corrosion Control Office (WR-ALC/CNC) has accepted PMB as an alternative paint stripping method to mechanical or chemical methods. General authorization is outlined in T.O. 1-1-8, "Application of Organic Coatings, Aerospace Equipment," which explains how to apply the process on metal and composite aircraft structures. Aluminum panels of 0.016-inch thickness are the minimum thickness structures allowed to be blasted using Type V. Ground support equipment is also authorized to be stripped by the PMB process. General authorization for paint removal must be followed by specific permission granted by the aircraft system manager through the weapon system specific technical data. Aircraft specific paint stripping process parameters are outlined in appropriate work control documents and aircraft peculiar (-23) technical manuals and specifications.

The Navy has authorized the use of PMB on metals only, including aluminum structure 0.016 inch or thicker. The Navy has not authorized PMB on structural composite materials yet, because structural effects testing has not been completed. However, the Navy does blast fiberglass surfaces on helicopters such as sponsons and fairings.

Concerns over fatigue life degradation due to PMB effects have been a major area of study. When depainting thick (0.060 inch and greater) aluminum skins, the blast stream peening effects have been found to be small and have caused minimal concern for fatigue life degradation, crack growth rate increase, or static mechanical property degradation. On the other hand, thin-skinned aluminum structures, such as 0.032-inch thickness and below, have demonstrated susceptibility to PMB-induced mechanical property degradation. Heavy particle contamination (sand or grit) in the PMB stream is thought to be the major contributor to fatigue initiation sites, while the PMB-induced residual stresses in the thin aluminum structure promote faster crack growth rates.

Blasting parameters on thin materials have been developed that minimize the peening effects, and are witnessed by use of 2024-T3, 0.032-inch thick, nonclad aluminum aero Almen strips subjected to reduction representative depainting blasting cycles. The use of these aero Almen strips allow a



measure of the blast stream peening effects, and are used for comparisons between process blasting parameters, blast medias, and blasting techniques to develop optimum stripping rates while maintaining acceptable blast effects on the substrates.

Composite materials have been evaluated and are considered in a similar vein to thin-skinned aluminum for their sensitivity to PMB effects. The concern has been that the blast media will contribute to interlaminar separation, delamination, and matrix resin cracking. Studies indicate the PMB process causes surface effects only. Delaminations have not been seen in test samples subjected to the most aggressive blasting parameters authorized in T.O. 1-1-8. Matrix cracking or separation between matrix resin and the structural fibers has not been demonstrated. However, removal of the soft resin from the surface of the composite is easily accomplished, so the problem in applying the PMB process is to exercise adequate control sensitivity through application of soft blast parameters in concert with formal operator training and demonstrable blasting skill. The rule of thumb on composites has been that, as long as the blasting process is controllable to the point where blast media does not erode through the resin and cause fiber damage, the process is acceptable. Fiberglass materials often use polyester resins as the matrix material. In this case the blast media and the paint system are made of harder material. PMB controllability becomes difficult in removing all of the topcoat without eroding some of the surface resin, thus requiring application of more resin to the surface before repainting. In this case experience has driven operators to mask sensitive areas so abrasive sanding methods can be used during post-blasting touch-up operations.

Blast-induced damage is a concern for some thin-skinned aircraft structures. PMB has been used to replace or augment chemical stripping operations for ground support equipment, ground vehicles, munitions, composite components, equipment trailers, cars, trucks, industrial equipment, and a host of other painted or coated surfaces. The concern over mechanical effects is prevalent in thin-skinned aircraft structure, while the concern for production efficiency is of greater concern for most other applications of PMB.

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## 2.0 PLASTIC MEDIA TYPES

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### 2.1 Description

Urea formaldehyde is a thermosetting amino resin formed by the controlled reaction of formaldehyde with various compounds that contain the amino group  $\text{NH}_2$ . Urea formaldehyde is supplied as a liquid, as a spray dried solid, and as a filled molding compound. The application of heat in the presence of acid catalysts converts these materials into hard, infusible products.

Urea resins are used in making rapid cure coatings as well as in the manufacture of resins and glues. In the case of glues, the urea resin is usually mixed with fillers such as pecan or walnut shells, wood flour, or a combination containing an acid catalyst for curing.

The urea currently being used as a plastic media for coatings removal is manufactured from urea molding compounds. Chemically purified alpha cellulose fibers are typically used in the manufacture of urea molded parts to increase strength, improve moldability and dimensional stability, and reduce molded-in stresses. Urea molding compounds may also contain other fillers such as glass fibers, chopped cotton, wood flour, and certain minerals.

Urea molding compounds are available with a wide range of flow, stiffness, and rate of cure parameters. Most commonly, urea formaldehyde molding compounds are cured in flatbed or rotary presses. Some formulations can be transfer molded, and special formulations have been developed for screw injection molding. Molding temperatures for ureas vary between 260°F and 340°F. Compression molding pressures vary from 2000-8000 psi.

Urea molding compounds provide good surface durability and hardness. Urea molded parts are chip and break resistant, heat resistant, and have good torque retention. Typically, these parts do not support combustion. Urea parts have good rigidity and load-bearing strength. They are generally resistant to organic solvents and have good electrical resistance.

Alpha cellulose-filled urea products are normally offered for sale to molders in granular form, although fine powder molding compounds are also used in selected applications. Alpha cellulose molding compounds used for the manufacture of urea formaldehyde Type II blasting media are manufactured by a number of companies including American Cyanamid, Perstorp, Plastics Manufacturing Company, MKB, Budd, and Patent Plastics.

Typical uses for alpha cellulose-filled urea formaldehyde molding compounds include the manufacture of wiring device parts (circuit breakers, wall plates, receptacles), closures or bottle tops (especially for the cosmetics industry), electric blanket control housings, toothpaste tube inserts, buttons, toilet seats, housings, knobs, and handles.

### **2.1.1 MATERIAL CHARACTERISTICS**

#### **GENERAL**

MIL-P-85891 Identification	- Type II
Melting Temperature	- N/A (thermoplastic)
Tensile Strength	- 5,500-13,000 psi
Compressive Strength	- 25,000-45,000 psi
Hardness	- Rockwell M 110-120
Specific Gravity	- 1.47-1.53

#### **SPECIFIC TO COATINGS REMOVAL**

Hardness	- Barcol 54-62 (Mohs' 3.5)
Ash Content, Maximum	- 0.5% (must not contain mineral fillers)
Chlorine Content, Maximum	- Trace (could come from water supply)
Iron Content, Maximum	- 0.05% (colorant related)
pH of Water Extract	- 4-8 (should be neutral)
Bulk Density	- 58-60 pounds per cubic foot
Substrate Temperature, Maximum	- 350°F
Ignition Temperature	- 530°F
Explosibility	- 0.085 ounces per cubic foot

### **2.1.2 GENERAL PERFORMANCE CHARACTERISTICS**

Urea formaldehyde was one of the plastic materials initially evaluated at Hill Air Force Base during the first half of the 1980s. It rapidly became the material of choice for use on the F-4 at Hill,

because of performance economics and the structure of the F-4 weapons system. The F-4 has very little soft, thin sheet aluminum and composite.

Urea formaldehyde, at 54-62 on the Barcol hardness scale, is soft enough that it has minimal surface distortion effect on 7075-T6 under normal blasting conditions of 30 to 40 psi and 18- to 24-inch standoff distance. On 2024-T3, urea formaldehyde has a more pronounced effect with surface distortion (peening effect) visible under 30X magnification. As shown in the Battelle data in Chapter 5, Almen intensity on 2024-T3 Almen strips ranges from 2 to 10 mils, depending on blast pressure, angle, and distance. The peening effect of urea formaldehyde on 6061 aluminum is more pronounced, with extended blasting resulting in a uniform distortion of the surface.

Urea formaldehyde is as hard as (or harder than) most composite resins and care must be taken when blasting composites not to go below the primer layer.

Urea formaldehyde is held together by the alpha cellulose, which actually behaves somewhat as a copolymer in the abrasive blast particles. Because of the alpha cellulose, the individual blast particles are blocky in shape with very rough surfaces. The rough surfaces cause an abrading away of coating systems, while the more angular corners of the particles chip away the coating.

In general, there is a fair amount of dusting when blasting with urea formaldehyde. As the particles break down during the blasting process, the alpha cellulose causes much of the dusting. Good cross ventilation in the blast room is required to minimize dusting during the blast process.

There are several manufacturers of urea formaldehyde Type II blast media. Most manufacturers indicate that they have incorporated an antistatic material to improve media flow in the blast system. In the case of multicolored ground reclaimed urea formaldehyde, the antistatic is a topical material that will come off and be removed by the dust collection system during blasting. Manufacturers providing virgin urea formaldehyde manufactured specifically for plastic media blasting applications claim to have an antistatic agent incorporated as an integral part of the media. In any case, whether the urea formaldehyde is virgin or recycled, static attraction problems are minimal and can be dealt with through proper grounding of the blast equipment and workpiece.

### **2.1.3 GENERAL APPLICATIONS**

Urea formaldehyde has emerged as the all-purpose workhorse plastic media. Applications for urea formaldehyde include, but are not limited to, the following:

- a. Aircraft Skin Coatings Removal. Approvals and applications are specific to the OEM manufacturer and the specific airframe/weapon system. In general, urea formaldehyde has been used on thicker, clad commercial aircraft skins and on other harder aircraft alloys.
- b. Aircraft Structural Components. Landing gears and wheels and other thick structural components requiring coating/contaminant removal.
- c. Ground Support Equipment in the Aircraft Industry.
- d. Contaminant removal - general; ash residue from bake-off; carbon removal from engine parts; oxidation on brass/copper/decorative parts; removal of investment casting residue.
- e. Industrial tool cleaning; rubber molds; plastic molds; tire molds; paper manufacturing tooling; resin removal from composites manufacturing tools; spray paint system cleaning; baking industry equipment cleaning; die cast mold cleaning—zinc/aluminum.
- f. Surface preparation applications; core defining in sand casting; deburring soft metals, plastics, and ceramics; deflashing die cast metals; deflashing molded thermoset plastic; etching printed circuit boards; prelamine roughening of composites/plastics; removal of heat treat scale from soft metals; resin bleed removal from electronic parts; surface prep of plastic prior to finishing.
- g. Nonaircraft coating/sealant removal; aluminum boats; automotive wheels; cast metals; coated ceramic tile; resin rich composites (with caution); fiberglass boats; ground vehicles (autos/vans/tractors/trailers; sheet metal structures (minimize warping); paint and varnish from hardwood furniture (not for pine); paint rejects in industrial finishing (if economics warrant).

#### **2.1.4 SPECIAL EQUIPMENT ISSUES**

Urea formaldehyde can be used in any direct-pressure blast system with minor modifications to ensure media flow. For surface critical applications (for example, aircraft thin sheet aluminum), the system should be dedicated to plastic media. Additionally, for critical applications, the recycling system should have a set of screens to ensure removal of oversized particles. Dense particle separators, currently available or under development, should also be incorporated for critical operations to assist in the removal of heavy/hard particles within the working mix size range.

Urea formaldehyde can be used in suction blast equipment as well, although control of media flow is more difficult. For nonsurface critical high volume applications, suction equipment may be preferred since it allows continuous blasting.

Ureas can be used in turbine wheel/centrifugal blasting systems. Wheel speed must be reduced and the wheel blades must be specially coated to minimize breakage of media when it comes in contact with the wheel blades.

A variable metering orifice is preferred for direct blast equipment, as it permits easy adjustment to mass flow during operation without changing blast pressure at the nozzle.

Grounding of the blast equipment and the workpiece is appropriate to minimize buildup of static dust during the blast operation.

## 2.2 Melamine Formaldehyde

Like urea formaldehyde, melamine formaldehyde is an amino resin formed by the controlled reaction of formaldehyde with various compounds that contain the amino group  $\text{NH}_2$ . The main difference between urea formaldehyde and melamine formaldehyde is that there is a greater amount of chemical cross-linking with melamine. Because of the additional cross-linking of melamine, a more stable resin results. Melamine is harder than urea and has greater resistance to temperature than urea. While molding temperatures for urea molding compounds are in the  $260^\circ$  to  $340^\circ\text{F}$  range, temperatures as high as  $360^\circ\text{F}$  may be used with melamines.

Melamine-based, alpha cellulose-filled molding compounds exhibit all the traits of urea, only some traits are more pronounced. Properly cured melamine moldings are not attacked by weak acids, alkalies, solvents, or water.

One of the major applications for melamine is as a laminating resin. Manufacturers of high-pressure decorative laminates prepare the resin syrup as needed, either directly from raw materials or by dissolving a spray dried resin in water. Melamine formaldehyde laminating resins are used to saturate such substrates as paper and cloth in special continuous manufacturing equipment. Low-pressure melamine laminating resins (250-300 psi) are used widely for furniture and vertical wall surfaces.

Applications for alpha cellulose-filled melamine molding compounds include molded dinnerware, buttons, ashtrays, lavatory bowls, utensil handles, shaver housings, appliance components, control buttons, and knobs. Wood flour-filled melamines are used for industrial electrical parts and military specifications. Glass- and mineral-filled melamines are used exclusively in certain military specifications.

The basic manufacturing process for alpha cellulose-filled molded melamine parts is the same as that for urea. However, higher temperatures and pressures are used and, in general, thicker parts are molded from melamine.

Manufacturers of alpha cellulose-filled melamine molding compounds include American Cyanamid, Perstorp, Plastics Manufacturing Company, MKB, Budd, and Patent Plastics. Additional companies manufacture liquid resins for the laminate industry as well.

### **2.2.1 MATERIAL CHARACTERISTICS**

#### **GENERAL**

MIL-P-85891 Identification	- Type III
Melting Temperature	- N/A (thermoset)
Tensile Strength	- 5,000-13,000 psi
Compressive Strength	- 33,000-45,000 psi
Hardness	- Rockwell M 115-125
Specific Gravity	- 1.47-1.52

#### **SPECIFIC TO COATINGS REMOVAL**

Hardness	- Barcol 64-72 (Mohs' 4.0)
Ash Content, Max	- 0.5% virgin, 2.0% recycled
Chlorine Content, Max	- N/A
Iron Content, Max	- 0.05% (related to colorants)
pH of Water Extract	- 4-8 (should be neutral)
Bulk Density	- 58-60 pounds per cubic foot
Substrate Temperature, Max	- 400°F
Ignition Temperature	- >530°F
Explosibility	- 0.09 ounces per cubic foot

### **2.2.2 GENERAL PERFORMANCE CHARACTERISTICS**

The basic difference between urea formaldehyde and melamine formaldehyde is the additional increment of hardness associated with the cross-linking of the polymer. Additionally, because of the cross-linking, melamine is stable at slightly higher temperatures. The small increment of hardness difference between melamine and urea is evident in visual evaluation of blasted surfaces as well as in

analysis of the arc height data. Melamine is also more friable and dustier when it breaks down in the blasting process. Like urea, use requires good cross ventilation in a blast room.

Melamine, because of its hardness, fell out of favor during the initial plastic media testing conducted at Hill AFB. Melamine has become more of a specialty material for use on harder substrates.

Almen arc height data as high as 14 mils were observed for melamine versus a maximum of 10 mils for urea. It should be noted, however, that at blast pressures as high as the 60 psi, the paint removal rate is so fast that excessive dwell time is taking place. The incorporation of robotics in paint stripping will allow the revisiting of melamine in lower pressure, smaller particle size ranges on certain alloys.

Melamine is too hard for use on 6061 aluminum, particularly in some applications involving thick coatings on structural parts. The blast pattern of melamine can be seen on 2024-T3 aluminum following a single blast cycle. While melamine has less surface distortion effect on 7075-T6, saturation blasting results in full visual coverage under 30X magnification.

An antistatic agent is incorporated by most manufacturers of melamine formaldehyde blast media (Type III in MIL-P-5891). As with urea, the antistatic is topical in recycled products and is an integral part of specially manufactured blast material. At this juncture, there is very little melamine being manufactured specifically for plastic media blasting, as the list of applications is not as broad as urea.

### **2.2.3 GENERAL APPLICATIONS**

As discussed earlier, melamine finds limited use on aircraft fuselage coating removal because of its hardness. Melamine has been successfully used at lower pressures and at shallow angles by some coating removal operators. However, because it is harder, melamine is more operator sensitive and requires greater control in use.

Principal applications for melamine formaldehyde are the same as those for urea in the nonaircraft skin market. Melamine finds considerable use in ground vehicles such as autos, vans, tractors, and trailers. Additionally, the Army maintenance command is using melamine to remove coatings from weapon systems and ground personnel carriers.

One application where melamine has an advantage over urea is in the tire industry. Molds can be cleaned at a higher operating temperature with melamine than with urea, thereby minimizing the amount of time that the tire mold must be off-line while it is being cleaned.



For most other applications, the melamine versus urea choice is based on the total economics of the operation. If melamine can do the job more cost-effectively than urea, it stands the chance of being the material of choice. However, since urea is used more broadly in applications, users sometimes sacrifice economics on a given application to minimize investment in plastic media inventory. Normally, if urea will do the job, it is used in general-purpose coating removal.

#### **2.2.4 SPECIAL EQUIPMENT ISSUES**

Melamine formaldehyde can be used in any direct-pressure blast system, with minor modifications to ensure media flow. For surface critical applications (i.e., aircraft thin sheet aluminum), the system should be dedicated to plastic media. Additionally, for critical applications the recycling system should have a set of screens to ensure removal of oversized particles. Dense particle separators, currently available or under development, should also be incorporated for critical operations to assist in the removal of heavy/hard particles within the working mix size range.

Melamine formaldehyde can be used in suction blast equipment as well, although control of media flow is more difficult. For nonsurface critical high volume applications, suction equipment may be preferred, since it allows continuous blasting.

Melamine can be used in turbine wheel/centrifugal blasting systems. Wheel speed must be reduced and the wheel blades must be specially coated to minimize breakage of media when it comes in contact with the wheel blades.

A variable metering orifice is preferred for direct-blast equipment, as it permits easy adjustment to mass flow during operation without changing blast pressure at the nozzle.

Grounding of the blast equipment and the workpiece is appropriate to minimize buildup of static dust during the blast operation. Higher dusting at equivalent blast pressures might call for improved ventilation with melamine.

## 2.3 Phenol Formaldehyde

Phenolic resin is manufactured by reacting formaldehyde and phenol to form a heat-cured thermoset material. The chemical structure is highly cross-linked, which gives it excellent properties. Phenol formaldehyde is used primarily in applications requiring heat resistance and close dimensional tolerances.

General-purpose phenolics are used in high-temperature electrical products such as ovens and toasters, ashtrays, wiring devices, switch gears, pulleys, and pot handles. Engineered phenolics are used in automotive applications such as water pumps, brake pistons, and electrical connectors. They are also used in seals and valves in down-hole oil drilling applications.

Phenolic resins are used in general-purpose molding compounds and in high-performance, engineering-grade materials. General-purpose compounds incorporate fillers, reinforcements, and phenolic resin. The fillers used include mica, clay, wood flour cellulose, mineral fibers, and chopped fabric. They are sold to the molder in a ready-to-be-molded state with the filler incorporated.

The engineering-grade phenolic resins typically are glass fiber reinforced. Sometimes, organic fillers are also used in the engineering-grade resins. Phenolic resins have the capability to be highly filled, sometimes with more than 70 percent filler and/or reinforcement.

Injection molding is most commonly used to process phenolic compounds. Short cycle times and low-waste factors combine to provide low-cost parts with excellent properties.

Compression molding, such as the process used to make melamine dinnerware, is still used to a certain extent in processing phenolics. The preheating and preforming of phenolics are undertaken to reduce cycle time in a compression molding operation.

There are a dozen or so different base formulations of phenol formaldehyde resins. Major manufacturers include Union Carbide, Monsanto, Reichold, Occidental, Fiberite, and Plastics Engineering.

The phenol formaldehyde included in MIL-P-85891 is presumed to be the cellulose-filled formula, which is similar to the urea and melamine formulations. Phenol formaldehyde is not currently being used in any quantity in PMB, because most of the available resins are filled with glass or other minerals.

### 2.3.1 MATERIAL CHARACTERISTICS

#### GENERAL

MIL-P-85891 Identification	-	Type IV
Melting Temperature	-	N/A (thermoset)
Tensile Strength	-	3500-6500 psi
Compressive Strength	-	22,000-31,000 psi
Hardness	-	Rockwell M 95-115
Specific Gravity	-	1.38-1.42

#### SPECIFIC TO COATINGS REMOVAL

Hardness	-	Barcol 54-62 (Mohs' 3.2-3.5)
Ash Content, Maximum	-	0.5% virgin, 2.0% recycled
Chlorine Content, Maximum	-	Trace
Iron Content, Maximum	-	0.05% (related to colorants)
pH of Water Extract	-	4-8 (should be neutral)
Bulk Density	-	N/A
Substrate Temperature, Maximum	-	N/A
Ignition Temperature	-	390°F
Explosibility	-	0.079 ounces per cubic foot

### 2.3.2 GENERAL PERFORMANCE CHARACTERISTICS

No technical data base exists on the phenol formaldehyde plastic blast media (Type IV in the Mil-Spec). It is assumed that some manufacturers in the early days of PMB were mixing phenolics with other resins in the manufacturing process.

Since there has been an excess of urea and melamine product available and because phenolic resins are usually glass filled, use has been limited.

As additional information becomes available, or if phenolics increase in use, this chapter will be amended.

### 2.3.3 GENERAL APPLICATIONS

It is assumed that phenol formaldehyde in the cellulose-filled form would serve the same applications as urea and melamine.

#### **2.3.4 SPECIAL EQUIPMENT ISSUES**

None at this time.

#### **2.3.5 OTHER ISSUES**

Care must be exercised in the use of phenol formaldehyde in the aircraft repainting industry, unless the material has been specifically formulated for the application. Glass- and mineral-filled products have a higher density and hardness, and can cause substrate damage. Asbestos-filled phenolic must be avoided in blasting for the obvious health hazard reasons. Cotton- and wood flour-filled phenolics will likely cause excessive dusting in a blasting application.

### **2.4 Polyester Rigid Cast Thermoset**

While urea, melamine, and phenol formaldehyde are cured under temperature and pressure, thermoset polyester cures in cast sheet form by being cooked. The type of starting material being used, manufacturing process control, and cooking temperature determine the final resin performance. The polyester material being used as Type I blasting media is unfilled cast sheet polyester. Pure cast sheet products make up a very small percentage of the total polyester market. They are generally used in combination with fillers and reinforcers such as fiberglass.

The construction market is one of the major consumers of polyester resin, as these products are used in the manufacture of cultured marble and onyx, sanitary ware, glass fiber-reinforced tub and shower units, building facades, specialty flooring materials, and decorative elements.

Polyester finds broad use in the transportation industry where sheet molding compound has been replacing metal parts for several years. Polyesters are being used in highway and bridge repair in the polymer concrete form. Polyesters are used in the business machine and portable hand tool industry where they are made into BMC and SMC molded parts. Because of its transparency to microwave radiation and thermal stability, polyester is able to compete in the microwave cookware industry. The marine industry is based almost entirely on parts based on glass-reinforced polyester resin. Ease of application and long life under adverse conditions makes fiberglass popular for these applications.

The button industry is the major user of unfilled cast sheet polyester. Use of the product as a blast media started with buttonholes, expanded to the chopping/grinding of off-specification buttons, and finally to making cast sheet polyester for the purpose of grinding up as a plastic abrasive media.

A half dozen major companies manufacture the majority of the rigid unfilled cast sheet polyester. Among the major suppliers are Reichold, Owens Corning, ICI, Cargill, and Shell.

## 2.4.1 MATERIAL CHARACTERISTICS

### GENERAL

MIL-P-85891 Identification	-	Type I
Melting Temperature	-	N/A (thermoset)
Tensile Strength	-	600-13,000 psi
Compressive Strength	-	13,000-30,000 psi
Hardness	-	Barcol 35-75
Specific Gravity	-	1.04-1.46

### SPECIFIC TO COATINGS REMOVAL

Hardness	-	Barcol 34-42 (Mohs' 3.0) (low end of above)
Ash Content, Maximum	-	0.5% virgin, 2.0% recycled
Chlorine Content, Maximum	-	Trace
Iron Content, Maximum	-	0.05% (colorant related)
pH of Water Extract	-	4-8 (should be neutral)
Bulk Density	-	45-48 pounds per cubic foot
Substrate Temperature, Maximum	-	250°F
Ignition Temperature	-	N/A
Explosibility	-	N/A

## 2.4.2 GENERAL PERFORMANCE CHARACTERISTICS

Polyester behaves differently than urea, melamine, and phenol formaldehyde in the plastic media blasting operation. Because the cast sheet product is unfilled, it forms much sharper points and flatter surfaces when it is chopped into blast particles.

In general, the polyester blast particles work by chipping away coatings and contaminants with their sharp edges. Unlike the filled amino thermosets, polyester does not abrade coatings. The density of polyester is much lower than urea and melamine. This, coupled with the more angular shape of the blast particles, makes it more difficult to get the material to flow uniformly in a blast system. Where

an antistatic is desirable with urea and melamine, an antistatic or flow agent is a necessity with polyester.

It has been demonstrated that polyester (Type I in MIL-P-89891) causes very low residual stress in 2024-T3 and 7075-T6 aluminum, even when blasted at pressures as high as 50 to 60 psi. It has also been shown, however, that the softer polyester removes aircraft coatings at a very slow rate.

Because polyester is unfilled and soft, it absorbs energy when it impacts a harder substrate. If the paint/coating system is well adhered and harder than the polyester, the coating will withstand the blasting process.

While urea and melamine abrade and cause dusting as they are used in blasting, polyester stays intact until a critical energy absorption level is reached. At that point, the unfilled polyester shatters into a number of very small fragments.

#### **2.4.3 GENERAL APPLICATIONS**

If melamine is the aggressive material and urea the general-purpose material, thermoset polyester can best be described as the most delicate of the thermoset plastic blast medias. While polyester can be used in many of the applications served by urea and melamine, it is not performance competitive in most processes.

The main applications for polyester are found in the electronics industry, where it is used to remove resin bleed from electronic parts. Polyester is also used in the deflashing of molded thermoset plastic. In certain applications, polyester can deflash plastics without affecting surface appearance. Fiberglass and composites can be blasted with polyester, but care must be taken to ensure that gel coat is left undisturbed.

Applications such as paint removal from wooden furniture and architectural items are also addressed with polyester.

#### **2.4.4 SPECIAL EQUIPMENT ISSUES**

As discussed, it is more difficult to get the lower density polyester to flow freely and evenly in the blast system. The material has a tendency to bridge in the pressure pot, and increased aeration of the pressure vessel may be required.

As the material must be used at high operating pressures to remove well-adhered coatings, heavy/hard particle separation equipment is important in critical substrate applications.

While well within acceptable ranges, thermoset polyester has a lower explosibility threshold than urea and melamine, and care should be taken to ensure adequate ventilation and minimization of dusting.

#### **2.4.5 OTHER ISSUES**

The user must make sure that the product used is manufactured from unfilled cast sheet polyester, if it is a critical application. Over 95 percent of the polyester products manufactured are filled with fiberglass or other mineral fillers. These fillers are hard enough to cause substantial damage to thin sheet soft aluminum alloys.

### **2.5 Acrylic**

Most acrylics begin with methyl methacrylate monomer (MMA). The monomer is polymerized by the free radical process with the addition of peroxide. Acrylics can be cast in sheet form, rods, or tubing shapes. Cast sheet is polymerized between glass plates through an exothermic reaction, which must be closely controlled to prevent voids in the finished product. Acrylics are known for their clarity and surface hardness. They have good weatherability, good light transmission, chemical resistance, toughness, and surface hardness.

Acrylic sheet is still being used today in one of its original applications—aircraft canopies and windows. It is fitting that this material has emerged as the current preferred material for many of the aircraft paint stripping applications with which we are faced.

Acrylics are modified with various ingredients to increase impact strength and, in some cases, to alter the refractive index of acrylic to match other materials in transparency. It can also be purchased in bead or pellet form for extrusion, injection, or compression molding.

Extruded sheet acrylic is available in a variety of thicknesses from 0.048 inch up to 0.250 inch. Extruded sheet and cast sheet are roughly equivalent in cost in the thicker sizes. Sheets of acrylic can be cut with power saws. Thinner sheet can be scribed and broken like glass. Because it is a thermoplastic, parts can be joined by a variety of welding techniques.

Acrylics are used to make signs, because they have excellent weatherability. Acrylic sheet is used as a safety glazing and as a replacement material for storm doors and patio doors. Insulated skylights are manufactured from acrylic, and the use of acrylic in the sanitary ware market has grown in recent years. One of the fastest growing applications for acrylic is in medical diagnostics, where acrylic is preferred because of clarity and excellent UV transmission.

Injection molding of acrylic can be accomplished on any conventional injection molding machine. Higher pressures are required, as the material is considered to be fairly viscous. Also, highly polished, chrome-plated molds are normally used to ensure a good surface finish on the molded part.

Acrylic molding compounds are used broadly in the automotive industry. Taillights comprise the principal application with other uses, including side markers, instrument covers, nameplates, trim, and dials. Acrylic is also used in appliance panels, display cases, and touch-tone phone buttons.

Acrylic plastic media is manufactured from cast or extruded sheet by cryogenic grinding techniques. The grinding process used to manufacture thermoset plastic abrasives creates too much heat for the thermoplastic acrylic material.

## 2.5.1 MATERIAL CHARACTERISTICS

### GENERAL

MIL-P-85891 Identification	-	Type V
Melting Temperature	-	194°-221°F
Tensile Strength	-	8000-11,000 psi
Compressive Strength	-	11,000-19,000 psi
Hardness	-	Rockwell M 80-100
Specific Gravity	-	1.17-1.20

### SPECIFIC TO COATINGS REMOVAL

Hardness	-	Barcol 46-54 (Mohs' 3.5)
Ash Content, Maximum	-	0.5% virgin, 2.0% recycled
Chlorine Content, Maximum	-	Trace
Iron Content, Maximum	-	0.05%
pH of Water Extract	-	4-8 (should be neutral)
Bulk Density	-	45-48 pounds per cubic foot
Substrate Temperature, Maximum	-	200°F
Ignition Temperature	-	734°F
Explosibility	-	0.079 ounces per cubic foot



### **2.5.2. GENERAL PERFORMANCE CHARACTERISTICS**

Acrylic media is currently the most commonly used plastic media. Polyester is not aggressive enough to achieve acceptable strip rates on many of the aircraft coating systems. Urea is considered by some to be too aggressive for certain thin sheet aluminum and composite applications.

Acrylic has a much harder surface than polyester, with a density equal to or slightly lower than polyester. There is very little dusting with acrylic, since it is an unfilled polymer. Acrylic is more resilient than urea and absorbs more energy, since it is an unfilled material.

An antistatic/flow agent is definitely required for acrylic blast material. Because of the low density, it tends to bridge up in the blast system. It also seems to have a tendency to clump up in the presence of moisture.

Some concerns exist about residual smear left by blasting with a thermoplastic material. The smear issue, however, may be the result of the antistatic used as a topical on recycled acrylic.

At this juncture, acrylic has emerged as the best available material for stripping coating from thin, soft aluminum alloys. The blast particles are very angular, like polyester, but are harder, and therefore do a better job of removing the coating.

### **2.5.3 GENERAL APPLICATIONS**

The general application for acrylic includes any thin sheet, soft alloy with a coating that must be removed. Deburring soft metals, plastics, and ceramics; deflashing die cast metals and molded thermoset plastic parts; removal of resin bleed from electronic parts; aircraft components made of aluminum, magnesium, and composites are also applications for acrylics. Acrylic may also be used on aluminum boats, automotive wheels, composites, fiberglass structures, and ground vehicles with fiberglass/composite bodies.

## **.5.4 SPECIAL EQUIPMENT ISSUES**

As discussed, the density and particle geometry of acrylic blasting material may cause it to bridge up in the system. Antistatic and flow agents are required with acrylic. Additionally, grounding of equipment and the workpiece is recommended to lessen static attraction.

## **2.5.5 OTHER ISSUES**

Residual smear remains an area of concern with the use of acrylic. In aircraft depainting applications, the surface is subjected to follow-on operations, which remove the smear.

## **2.6 Allyl Diglycol Carbonate**

The allyl esters are available as low viscosity monomers and thermoplastic prepolymers. Allyls are used as cross-linking agents for unsaturated polyesters and in the preparation of reinforced thermoset molding compounds and high-performance transparent parts. Allyl resins have good electrical properties under high temperature and humidity. Molded parts have dimensional stability, chemical resistance, mechanical strength, and good heat resistance. Allyls are used primarily in molding compounds and in preimpregnated glass cloths and papers. Molding grades of allyl resins are typically available in glass, mineral, and synthetic fiber-filled types.

Allyl carbonates, such as the material from which Type VI blasting material is manufactured, are used when optical transparency is required. It is the primary material used in the manufacture of plastic lenses for eye wear, because it is lightweight and has dimensional stability and transparency.

Other applications for allyl carbonates include instrument panel covers, camera filters, and a variety of glazing applications.

Allyl compounds also find use in electric connectors in communications, computer, and aerospace systems. Reinforced resins are found in tubing, ducting, radomes, junction boxes, and aircraft and missile parts.

The allyls monomer is also used to cross-link polyester. Because of the low volatility of allyls, allylic polyesters can be molded at higher temperatures than styrene-based polyesters.

Glass- and mineral-filled allyl molding compounds are made by a number of manufacturers. The allyl diglycol carbonate cast sheet that Type VI media is made from is manufactured primarily by PPG Industries.

## 2.6.1 MATERIAL CHARACTERISTICS

### GENERAL

MIL-P-85891 Identification	-	Type VI
Melting Temperature	-	N/A (thermoset)
Tensile Strength	-	5000-6000 psi
Compressive Strength	-	21,000-23,000 psi
Hardness	-	Rockwell M 95-100
Specific Gravity	-	1.3-1.4

### SPECIFIC TO COATINGS REMOVAL

Hardness	-	Barcol 30-40 (Mohs' 3.0)
Ash Content, Maximum	-	0.5% virgin, 2.0% recycled
Chlorine Content, Maximum	-	Trace
Iron Content, Maximum	-	0.05% (should be zero)
pH of Water Extract	-	4-8 (should be neutral)
Bulk Density	-	52-54 pounds per cubic foot
Substrate Temperature, Maximum	-	300°F
Ignition Temperature	-	710°F
Explosibility	-	N/A

## 2.6.2 GENERAL PERFORMANCE CHARACTERISTICS

Like acrylic and thermoset polyester, allyl carbonate is unfilled. When ground into blasting media, it forms particles with very sharp edges.

Claims are that Type VI can be used at lower operating pressures than acrylic. This may be in part because of particle geometry (sharper edges). Specific gravity may also contribute to Type VI's ability to work under lower operating pressures. Allyl is between acrylic and urea in density (acrylic, 1.17-1.20; allyl, 1.3-1.4; urea, 1.47-1.54), but overlaps acrylic on the Rockwell M hardness scale (acrylic, M 80-100; allyl, M 95-100). Interestingly, MIL-P-85891 shows allyl as having a Barcol hardness equivalent to polyester, while its Rockwell hardness is at the top end of the acrylic range.

This is the only material of the six types in MIL-P-85891 where Rockwell hardness and Barcol hardness do not compare.

### **2.6.3 GENERAL APPLICATIONS**

Allyl diglycol carbonate overlaps the applications covered by thermoset polyester and acrylic. It is recommended for blasting on composites, aircraft components made of aluminum and magnesium, aircraft fuselage and missile skins, and fiberglass structures. Allyl can also be used to strip ground vehicles (autos, vans, tractors, trailers, etc.). Because of its good cutting action and low hardness, it works well in the removal of decals from sensitive substrates. Allyl can also be used to remove paint and varnish from hardwood furniture and architectural items.

### **2.6.4 SPECIAL EQUIPMENT ISSUES**

Like acrylic and polyester, allyl blast media requires an antistatic agent to ensure flowability. As it is designed to be used at lower pressures, the equipment must be capable of maintaining acceptable mass flow rates at pressures in the 20-25 psi range. Pulsing must be avoided when working on sensitive substrates.

### 3.0 PLASTIC MEDIA COMPARISON

This section briefly compares material data, Almen arc height data, and consumption rates.

#### 3.1 Material Data

Table 3.1 shows material requirements in a brief side-by-side comparison.

TABLE 3.1 INFORMATION ON MIL-P-85891 CLASSED MEDIA						
GENERAL						
Medium Name	Polyester (Thermoset)	Urea Formaldehyde (Thermoset)	Melamine Formaldehyde (Thermoset)	Phenol Formaldehyde (Thermoset)	Acrylic (Thermo- plastic)	Allyl Diglycol Carbonate (Poly (Thermoset)
MIL-P-85891 Identification	Type I	Type II <sup>1</sup>	Type III	Type IV	Type V	Type VI
Melting Temperature, °F	N/A	N/A	N/A	N/A	194-221	N/A
Tensile Strength, psi	600-13,000	5,500-13,000	5,000-13,000	3,500-6,500	8,000-11,000	5,000-6,000
Compressive Strength, psi	13,000-30,000	25,000-45,000	33,000-45,000	22,000-31,000	11,000-19,000	21,000-23,000
Hardness, Rockwell M	35-75 <sup>2</sup>	110-120	115-125	95-115	80-100	95-100
Specific Gravity	1.04-1.46	1.47-1.53	1.47-1.52	1.38-1.42	1.17-1.20	1.3-1.4
SPECIFIC TO COATINGS REMOVAL						
Hardness, Barcol (Mohs) <sup>3</sup>	34-42 (3.0)	54-63 (3.5)	64-72 (4.0)	54-62 (3.2-3.5)	46-54 (3.5)	30-40 (3.0)
Ash Content, Max., % by wt.						
Virgin, Grade A						
Recycled, Grade B	0.5	0.5	0.5	0.5	0.5	0.5
	2.0	2.0	2.0	2.0	2.0	2.0
Chlorine Content, Max., %	Trace	Trace <sup>3</sup>	N/A	Trace	Trace	Trace
Iron Content, Max., % by wt.	0.05 <sup>4</sup>	0.05 <sup>4</sup>	0.05 <sup>4</sup>	0.05 <sup>4</sup>	0.05	0.05 <sup>5</sup>
pH of Water Extract <sup>6</sup>	4-8	4-8	4-8	4-8	4-8	4-8
Extract Content, Max.	5.0	1.0	1.0	1.0	100	1.0
Water Absorption Max., % by wt.	2.0	10.0	10.0	10.0	2.0	2.0
Bulk Density, lbs/cu ft	45-48	58-60	58-60	N/A	45-48	52-54
Specific Gravity	1.15-1.25	1.47-1.52	1.47-1.52	1.47-1.52	1.10-1.20	1.28-1.33
Heavy Particles Max., % by wt.	0.02	0.02	0.02	0.02	0.02	0.02
Light Particles, Max., % by wt.	0.1	1.0	1.0	1.0	0.1	0.1
Substrate Temperature Max., °F	250	350	400	N/A	200	300
Ignition Temperature, °F <sup>7</sup>	N/A	530	> 530	390	734	710
Explosibility, oz/cu ft <sup>7</sup>	N/A	0.085	0.09	0.079	0.079	N/A
<sup>1</sup> Must not contain mineral fillers. <sup>5</sup> Should be zero. <sup>2</sup> Value is Barcol hardness. <sup>6</sup> Should be neutral. <sup>3</sup> Could come from water supply. <sup>7</sup> From Composition Materials Co., Inc., Technical Data Sheet. <sup>4</sup> Colorant related.						

**TABLE 3.1.1 ALMEN STRIP ARC HEIGHTS FOR 2024-T3 BARE ALUMINUM**

		Media										
		Type I			Type II				Type III			
		Pressure			Pressure				Pressure			
		30 psi	40 psi	60 psi	20 psi	30 psi	40 psi	60 psi	20 psi	30 psi	40 psi	60 psi
Standoff Distance	Angle, degree	Median of Arc Height, Mils			Median of Arc Height, Mils				Median of Arc Height, Mils			
12	30	1	1	2	4	5	7	9	5	6	6	7
	45	3	2	2	6	5	-	6	5	6	6	9
	60	2	2	2	6	5	6	6	6	8	7	11
	90	2	1	2	5	7	6	6	9	12	9	11
18	30	1	1	1	3	3	6	7	5	5	5	6
	45	1	1	1	5	7	7	6	5	7	7	8
	60	1	1	1	5	7	6	7	6	6	10	12
	90	1	1	1	6	6	8	7	10	8	11	11
24	30	1	0	1	4	3	6	5	5	5	5	5
	45	1	0	1	4	6	5	5	5	7	5	5
	60	-	1	0	5	6	6	8	5	6	8	8
	90	-	3	1	5	6	7	6	6	10	8	8
30	30	-	-	1	3	3	4	5	4	6	5	4
	45	-	-	-	4	5	6	7	5	5	5	6
	60	-	0	-	5	5	5	8	8	6	7	7
	90	-	-	-	5	6	7	5	6	10	7	6

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## 4.0 PMB EFFECTS OVERVIEW

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The possibility of damage to structural materials is one of the major concerns in the use of plastic media blasting (PMB) on aerospace systems. A number of research efforts in government and in the aerospace industry have focused on this issue. This chapter outlines significant findings on the effects of PMB on substrate material properties.

The severity of damage to substrate materials is highly dependent upon the characteristics of the material and the PMB process parameters. Material properties, such as hardness, ductility, and resistance to cracking, contribute to damage levels. Design factors, such as the thickness of the part and the layup of composite materials, may also affect the damage severity. Process parameters that may influence substrate damage include: standoff distance; angle of attack; the type, size, and hardness of plastic media; blasting pressure; and dwell time. Since materials and process parameters must be taken into account when analyzing PMB-induced damage, information about these factors also is included in the discussions as necessary.

Concerns about PMB effects on substrates have centered around mechanical properties under static and fatigue loading. Other potential effects include changes in airflow characteristics of the vehicle due to surface roughening, erosion of cladding or anodize coatings, poor adhesion of paint following PMB, and changes in corrosion behavior. Also, surface deformation during PMB could cover fatigue cracks and prevent detection during nondestructive inspection (NDI).

In composite substrates, there are concerns that the blasting process may cause erosion of the surface gel coat, microcracking in the matrix material, fiber damage, and delamination or disbonding within the material.

It is often difficult to determine the amount and seriousness of PMB-induced damage to materials. Effects on mechanical properties may be so small that they cannot be distinguished from normal data scatter. Thus, statistical analysis of data is necessary to provide a high level of confidence that observed effects on properties are not coincidental. Several factors must be considered when evaluating test results referenced in this chapter:

- a. Mechanical testing of materials, particularly fatigue testing, inherently yields scattered data.
- b. The design and operation of a given component influences the criticality of damage induced by PMB. Flight-critical or fatigue-prone structures may require tighter control of induced effects in order to authorize PMB for use on these structures, whereas more liberal allowances may be made for ground equipment or structures with high tolerance to damage.
- c. In some cases, the effects of PMB are less damaging than alternative paint stripping methods such as hand sanding.
- d. The amount of damage to a material is highly dependent on the process parameters, the type of material being stripped, and operator technique.

## **4.1 Standard Test Methods**

This section contains information on standard test methods used to measure the effects of PMB on material properties. Interpretation of the data resulting from these tests is an important consideration. Since the properties of a given material vary naturally to some degree, statistical analyses are usually required in order to detect changes that are caused by PMB. Materials property tests, particularly fatigue and corrosion tests, inherently yield scattered data.

An Engineering Qualification Plan (EQP) is currently being prepared by the Air Force and will be published as an Air Force Guidance Specification. It will furnish specific test methods in addition to those general methods listed below.

### **4.1.1. MECHANICAL PROPERTIES OF METALS**

ASTM E206      Fatigue Testing and the Statistical Analysis of Fatigue Data

Description:    Guidance for analysis of fatigue test data.

ASTM E647-86a    Measurement of Fatigue Crack Growth Rates

Description:    Method to determine steady-state fatigue crack growth rates using compact-type or center-cracked tension specimens.



**ASTM E466-82    Conducting Constant Amplitude Axial Fatigue Tests of Metallic Materials**

**Description:**    Procedure for performance of axial fatigue tests to obtain fatigue strength of metallic materials in the fatigue regime where the strains are predominantly elastic (high cycle fatigue).

**4.1.2. MECHANICAL PROPERTIES OF COMPOSITE MATERIALS**

**ASTM D790-84    Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials (Method II: Four-Point Flexure)**

**Description:**    Test for flexural strength and modulus of fiber-reinforced composites. The four-point method is recommended, since it produces a larger area under uniform, maximum stress than the three-point method.

**ASTM D2344-84    Apparent Interlaminar Shear Strength of Parallel Fiber Composites by Short Beam Method**

**Description:**    Test for apparent interlaminar shear strength of unidirectional, fiber-reinforced composites. Because much of the specimen is under a nonuniform stress state, specimens do not always fail in interlaminar shear, especially when testing high strength composites such as graphite/epoxy. A four-point bend test on a 16 ply specimen with 16 to 1 span-to-depth ratio is an alternative test that may yield interlaminar failures.

**ASTM D3039-76    Tensile Properties of Fiber-Resin Composites**

**Description:**    Test for tensile properties of unidirectional or symmetrical laminates of fiber-reinforced composites.

**ASTM D 3410    Standard Test Method for Compressive Properties of Uni-Directional or Crossply Fiber-Resin Composites**

**Description:**    Test for compressive properties in fiber-reinforced composites. Three alternate test fixtures are described. The IITRI fixture is most widely used.

**4.1.3. CORROSION PROPERTIES**

**ASTM B 117    Salt Spray (Fog) Testing**

**Description:**    Accelerated test for uniform corrosion.

ASTM G16      Applying Statistics to Analysis of Corrosion Data

Description:    Guidance on analysis of corrosion test data.

ASTM G31      Laboratory Immersion Corrosion Testing of Metals

Description:    Accepted procedures for laboratory immersion corrosion tests, particularly mass loss tests.

ASTM G34      Standard Test Method for Exfoliation Corrosion Susceptibility in 2XXX- and 7XXX-Series Aluminum Alloys (EXCO Test)

Description:    Accelerated test for exfoliation corrosion (a form of localized corrosion) in 2XXX- and 7XXX-series aluminum.

ASTM G46      Standard Recommended Practice for Examination and Evaluation of Pitting Corrosion

Description:    Provides assistance in the selection of procedures for identification and examination of pits and evaluation of pitting corrosion, a form of localized corrosion.

#### **4.1.4. PAINT ADHESION TESTS**

FED STD 141,  
Method 6301      Adhesion (Wet) Tape Test

Description:    Used to determine innercoat and surface adhesion of organic coatings immersed in water.

### **4.2 Effects on Metal Substrates**

Plastic media blasting (PMB) effects metal substrates in two general ways:

- a.    It induces surface residual compressive stresses in the material (peening effect).
- b.    It roughens or erodes the surface.

The criticality of these effects depends on the type of metal being blasted and the design and use of the metal component. For aluminum alloys with thicknesses greater than 0.060 inch, the peening effect does not induce significant damage to the material's fatigue properties. Depending on the specific metal alloy, temper, and thickness, PMB can cause significant changes in fatigue behavior of metals,

particularly if the process is not tightly controlled to minimize damage due to excessive blast pressures, dwell time, or hard contaminants in the media. Thin metal substrates are known to be susceptible to oil canning under normal PMB operating parameters. Surface roughening and erosion caused by PMB may damage protective materials such as cladding or anodize coatings. However, surface roughness changes after PMB have not been shown to affect the aerodynamic efficiency of aircraft; any increases in roughness are within standards for current metal-skinned aircraft after repainting.

#### **4.2.1. SURFACE DAMAGE**

PMB can deform the surface of materials and erode protective anodize coatings and cladding material. Several studies noted microcracking and removal of sulfuric acid anodize on aluminum caused by PMB.<sup>[4,10,23]</sup> Erosion of cladding on 7075-T6 aluminum was also observed.<sup>[8,23,30]</sup>

On Alclad substrates PMB causes deformation in the clad surface, forming laps of material.<sup>[8]</sup> This causes an increase in surface roughness after the first blast cycle, but subsequent cycles tend to decrease this roughness by eroding the soft material from the surface.<sup>[4,8]</sup> An average of 6-17 percent of the clad layer was eroded in one study, with isolated areas of 80 percent erosion.<sup>[30]</sup> Also, 14-20 weight percent of the cadmium plate on cadmium-plated steel was eroded in another study.<sup>[23]</sup>

Surface pits, scratches, or defects also provide sites for fatigue crack initiation, thus increasing the chance of an early fatigue failure and providing sites for the initiation of corrosion.

#### **4.2.2. RESIDUAL STRESS**

The impact of the beads on a metal surface during PMB induces compressive stress in the surface of the material similar to the effects of shot peening. Beneath the compressed surface layer, a region of tension is formed to balance the compressive stress. In a thin, unconstrained specimen, the back surface of the specimen will also be in compression, and the resulting moment causes the specimen to bend. This deformation is measured as Almen arc height. In a constrained specimen, this deformation is prevented, and the force balance yields a tensile stress at the back surface.

These stresses are responsible for the deformation of constrained structures called oil canning that result from excessively aggressive PMB process parameters. The surface compressive stress may increase fatigue life in some components, while subsurface tensile regions accelerate fatigue crack growth.

The amount of residual stress and the depth of the compressive and tensile regions depend on the modulus of the material being blasted, the PMB process parameters (higher Almen arc heights means greater stress), and the number of PMB cycles the material was exposed to.

Stress magnitudes can be calculated using Almen arc height measurements on Almen test strips or strain gage measurements on structures. Stress can also be measured using X-ray diffractometry.

Battelle researchers measured stress using strain gages on Almen test strips. They recorded a maximum strain of about 250 microstrain, corresponding to about 2.5 ksi compressive stress.<sup>[8]</sup> The Oklahoma City ALC study used both Almen strip data and strain gage readings from structural elements to determine induced stress levels and depth of the compressive stress. They calculated compressive stresses of about 20 ksi on the surface of a 2024-T3 aluminum structure to a depth of 0.0035 inch. The compressive stress on a 7075-T6 panel was about 29 ksi, with a depth of 0.002 inch.<sup>[30]</sup>

Data also indicate that residual stress increases with successive blast cycles up to a maximum after about four blast cycles.<sup>[30]</sup> This corresponds to the saturation effect observed in Almen strip testing.

#### **4.2.3. TENSILE, COMPRESSIVE, OR FLEXURAL PROPERTIES**

There is no reported evidence of degradation of tensile, compressive, or flexural properties of metals due to plastic media blasting.

#### **4.2.4. FATIGUE PROPERTIES**

Fatigue is the most common cause of failure of aircraft structural components. In addition, many flight-critical components are designed using the damage tolerance design approach, which relies heavily on knowledge of the fatigue behavior of materials. Thus, any change in fatigue properties could drastically alter the life of the component and the chances of premature failure.

##### **4.2.4.1 Introduction**

PMB effects the regions of a structure at or near the painted surface. Several studies have shown that the process can increase the surface roughness of the material, particularly if the material being

blasted is relatively soft (i.e., aluminum cladding), and/or the blasting parameters are severe (hard media, or media contaminated with hard particles, high blast pressure, and close standoff distance). Irregularities in the surface can act as sites for fatigue crack initiation. In several PMB studies, hard contaminant particles in the media, such as sand, became imbedded in the surface of the material and initiated cracks, which caused a significant decrease in fatigue life of the specimens. These studies emphasized the importance of keeping the blast media free of contamination.<sup>[4,8]</sup>

The PMB process also induces residual stresses in the region near the surface of the material, similar to those produced by shot peening. The impact of beads on the material causes the surface to be compressed and creates regions of compressive and tensile forces below the surface of the material. Peening may increase the fatigue life of the material, since the surface is in compression, and this tends to discourage crack initiation and growth. However, below the surface, there is a region of tension. If a crack is present in this region, it will grow faster than a crack in a region with no stress. Thus, researchers have examined both the rate of growth of preexisting cracks in the structure after PMB (known as fatigue crack growth rate) and the total number of cycles to failure (known as fatigue life). Fatigue life includes both the cycles to initiate the crack and the cycles to cause the crack to grow large enough to cause failure.

#### **4.2.4.2 Fatigue Life**

Researchers reported no statistically significant reduction in fatigue life of undamaged, unnotched aluminum alloy specimens with thicknesses greater than about 0.06 inch.<sup>[4,8,9,20,27,29,30]</sup> In fact, some researchers reported an increase in fatigue life after PMB due to surface compressive stress.

Some studies indicated a decrease in fatigue life of thinner specimens. In a study performed by AFWAL (now Wright Laboratory), particles of sand and hard contaminants were present in the media.<sup>[4]</sup> These particles embedded themselves in the material surface and served as fatigue crack initiation sites, thus causing a reduction in fatigue life. Also, this decrease in fatigue life only occurred in specimens blasted at the lower pressure of 38 psi rather than 60 psi, probably because dwell time was longer for the 38 psi experiment, which allowed a greater number of contaminant particles to strike the surface. In addition, fatigue life degradation increased with multiple PMB stripping cycles. Similar decreases in fatigue life of aluminum were observed by Deel, Galliher, and Taylor,<sup>[8]</sup> and were attributed to the influence of contaminants. In a follow-on study, they used virgin media (not recycled

and hence not as heavily contaminated) to blast the specimens and found no significant decrease in fatigue life.

Specimens with holes, notches, cracks, or flaws were most affected by PMB. A study performed by Oklahoma City ALC Engineering Laboratory reported that PMB reduced the average fatigue life of notched 0.032-inch-thick 2024-T3 aluminum specimens by 66 percent. The fatigue life of 0.040-inch notched specimens of 7075-T6 aluminum decreased 27 percent and 38 percent for nonclad and clad specimens, respectively.<sup>[30]</sup> The General Dynamics study on F-16 materials also reported a decrease in fatigue life of specimens with drilled holes.<sup>[20]</sup>

Increases in fatigue crack growth rate (FCGR) were reported by a number of researchers.<sup>[8,9,20,30]</sup> The amount of increase varied with several factors:

- a. Specimen thickness: thinner specimens generally were most affected by PMB.
- b. Stress intensity factor: higher stress intensity factors (longer crack lengths) showed more acceleration of FCGR due to PMB.
- c. Blasting pressure: in general, higher pressure caused greater increases in FCGR, but as pressure is decreased, dwell time becomes a significant factor.
- d. Media contamination: Battelle's studies showed that the presence of hard contaminants accelerates FCGR.
- e. Type of alloy: 2024 aluminum alloys showed greater increases in FCGR than 7075 aluminum alloys.

In thin (0.06-inch thick or less) 2024 aluminum alloys, increases in FCGR of as much as 10 percent were reported by General Dynamics,<sup>[20]</sup> and as much as 120 percent by Oklahoma City ALC.<sup>[30]</sup> Battelle reported FCGR increases of about 40 percent for 0.016-inch-thick 7075-T6 aluminum specimens blasted with virgin media at 40 psi,<sup>[9]</sup> while Oklahoma City ALC found no effects on FCGR in the same alloy, which was 0.040-inch thick and subjected to 60 psi blast pressure.<sup>[30]</sup>

#### 4.2.4.3 Summary

In general, PMB effects on fatigue life of undamaged, unnotched components with thicknesses greater than 0.06 inch is negligible. Thinner substrates may suffer a decrease in fatigue life due to PMB, especially if they are subjected to aggressive blasting conditions or exposed to blasting media

containing hard contaminants. In addition, if flaws, holes, or large cracks are present in the material, PMB may accelerate the growth of cracks.

In order to reduce damage to fatigue properties, PMB process parameters must be chosen to induce the least amount of stress possible in the surface of the material. Higher peening stresses are related to an increase in fatigue crack growth rate.

#### **4.2.5. CORROSION PROPERTIES**

Research by the NAVAIR Engineering Support Office at the Naval Air Rework Facility (Pensacola),<sup>[23]</sup> and the Air Force Corrosion Program Office<sup>[10]</sup> indicates that corrosion rates in bare aluminum alloys (7075 and 2024 series) are not adversely effected by PMB. However, there is evidence in both studies that PMB causes cracks in anodize coatings and removal or damage to cladding. This damage changes the material's corrosion behavior and may cause future corrosion problems, if protective coatings are not reapplied. In addition, the NAVAIR study showed that PMB caused pinhole penetration of cadmium plating on steel, which led to increased corrosion.

#### **4.2.6. PAINT ADHESION**

There were no reports of significant degradation of adhesion of MIL STD aircraft paint systems to substrates following PMB of aluminum substrates.

### **4.3 Effects on Composite Substrates**

Composite materials currently used in aircraft are composed of continuous high strength fibers bound together by a relatively low strength polymeric resin. Since the fibers are aligned unidirectionally within a ply, the mechanical properties of that ply are anisotropic. The material is much stronger in the direction parallel to the fibers than in the direction perpendicular to the fibers.

In most composite structures, plies are stacked on one another in various orientations to make the properties of the material more isotropic. However, some of the properties of the material are limited by the strength and integrity of the fibers (fiber-dominated properties), while others depend on the properties of the matrix material (matrix-dominated properties). For example, tensile properties are typically fiber dominated, whereas compressive and interlaminar properties are matrix dominated. The

matrix also controls the resistance of the material to environmental influences such as moisture, solvents, and heat.

Plastic media blasting (PMB) tends to erode the surface of composite materials. Since the matrix is often a brittle material (such as an epoxy) that has the same hardness as the paint coating being removed, it may be eroded or cracked by the impacting beads. If significant amounts of the matrix are eroded or the matrix is cracked, the matrix-dominated properties of the material may suffer. Very small cracks (called microcracks) can effect the matrix-dominated properties and are difficult to detect with NDI. In extreme cases, PMB also damages the fibers. This can cause degradation of fiber-dominated properties, especially if the damage is extensive through one or more plies. Disbonds (separation at the fiber/matrix interface) also cause degradation in matrix-dominated properties.

Composites are also subject to subsurface impact damage, such as delaminations. These occur when adjacent plies separate from one another. Delaminations can grow under applied stress until the material essentially peels apart.

The results of experiments using PMB on composites indicate that blasting parameters must be less severe than those used on metal substrates and must be carefully controlled to prevent damage. The relationship between several PMB factors and damage in composites has been demonstrated in a number of studies. These factors include:

- a. Dwell time: longer dwell times or multiple strip cycles increase substrate damage.
- b. Stopping the stripping process at the primer layer: less damage is induced if the composite is only stripped to the primer layer. This is due to the reduced dwell time and the fact that a protective layer is left on the material.
- c. Media hardness: Type II media (3.5 Mohs' hardness) is more damaging than Type I (3.0 Mohs' hardness).
- d. Blast angle: shallow angles produce more damage than blasting that is done normal to the substrate surface.
- e. Pressure and standoff distance: higher pressures and closer standoff distances generally produce more damage, but since these factors may also effect strip rate (dwell time), a trade-off must be done between these effects to determine the optimum parameters.



#### 4.3.1. SURFACE DAMAGE

The most direct method of subjectively determining the amount of damage to a composite material is by examination or by inspection of the surface using optical microscopy or Scanning Electron Microscopy (SEM) or by inspection of the bulk of the material for cracks and delaminations using nondestructive inspection (NDI) techniques such as ultrasound and X-ray. Degradation in mechanical properties due to the blasting process is linked to the observed amount and type of damage done to the material.

All of the studies reported surface damage to varying degrees, depending on the process parameters used. Extensive surface damage was reported in the Naval Air Development Center (NADC) study.<sup>[18]</sup> After an extended dwell (five times longer than necessary for paint removal) PMB cycle using Type II (3.5 M) media at a pressure of 35 psi and a blast angle of 45° from vertical, severe fiber damage was observed. The AFWAL (now Wright Laboratory) study<sup>[4]</sup> also produced extensive fiber damage (up to 10 fiber diameters deep) after four PMB cycles at 60 psi with Type II media. General Dynamics evaluated PMB effects on a thin graphite/epoxy composite component with a fiberglass scrim ply to determine if the process was suitable for use on the F-16. Erosion extended through the scrim ply and into the topmost fibers of the underlying composite. These panels were stripped six times with Type II media at 35 psi and a 40° angle.<sup>[20]</sup>

Some studies reported evidence of matrix microcracking in the resin-rich area near the surface of the composite.<sup>[4,18]</sup>

Most studies reported erosion of the surface gel coat and little or no fiber damage on the first strip cycle. Repeated cycles produced further erosion. When the stripping process was stopped at the primer layer, no significant surface damage was found, even after four PMB cycles.<sup>[3]</sup>

In composites containing Kevlar® fibers, fuzzing of the fibers was evident in a Navy study of PMB paint removal on the AV-8B aircraft.<sup>[28]</sup> These fibers were used as stitching on the surface of the composite, and the damage did not effect the structural properties of the material.

The technicians were instructed to strip only to the primer layer, and very little damage to graphite fibers or the epoxy matrix was noted.

#### **4.3.2. SUBSURFACE DAMAGE**

Subsurface damage in composites, such as delamination (separation of adjacent plies), disbonds (separation at the fiber/matrix interface), and cracking, can be detected with NDI techniques such as ultrasound or X-ray or by microscopic examination of a cross section of the material. This type of damage can be very dangerous in a composite component, since it cannot always be detected by visual inspection of the surface, and it may cause extreme degradation of mechanical properties.

Bead blasting did not cause any damage below the surface plies in any of the studies under any process conditions. Researchers used a variety of methods to inspect for subsurface damage, including X-ray, ultrasound, and microscopic examination of cross sections.

These methods were also used to examine honeycomb core structures with composite skins that were subjected to PMB. No disbonds were observed between the core and skin materials.

#### **4.3.4. TENSILE AND FLEXURAL PROPERTIES**

None of the studies indicated any significant PMB-induced degradation in fiber-dominated properties (tensile and flexural strength and modulus parallel to the fiber direction) in unidirectional laminates.

Matrix-dominated properties, such as unidirectional tensile and flexural strength in a direction perpendicular to the fibers, were more scattered after PMB in the WRDC (now Wright Laboratory) study, although no statistically significant average degradation was noted.<sup>[3]</sup> Statistically significant decreases in 90° unidirectional flexural strength were noted in the AFWAL (now Wright Laboratory) study, as well as wide scatter in the data.<sup>[4]</sup> This was seen as evidence that microcracking was occurring in the matrix material.

The mechanical properties of quasi-isotropic (QI) or multidirectional laminates do not display as much degradation due to PMB, since their properties are not purely matrix- or fiber-dominated, as in the unidirectional composites. However, decreases in flexural strength of QI or multidirectional laminates with 90° surface plies were noted by the AFWAL (now Wright Laboratory) researchers.<sup>[4]</sup>

#### **4.3.5. COMPRESSIVE PROPERTIES**

PMB caused degradation of compression strength in some cases when high pressures (60 psi) and relatively hard media were used. WRDC (now Wright Laboratory) and Oklahoma City ALC reported a slight decrease in unidirectional compressive strength, when specimens were blasted at 60 psi with Type I Media.<sup>[3,21]</sup> Compression strength is a matrix-dominated property.

#### **4.3.6. INTERLAMINAR SHEAR STRENGTH**

Significant decreases in interlaminar shear strength (ILSS) were observed for unidirectional and quasi-isotropic specimens, when blast pressures were 60 psi or greater. ILSS is a matrix-dominated property.

#### **4.3.7. FATIGUE PROPERTIES**

The General Dynamics F-16 study examined PMB effects on fatigue properties of composites. The researchers found no evidence of significant fatigue life reduction or increase in fatigue crack growth rate after blasting a thin graphite/epoxy laminate based on the design of the F-16 horizontal stabilizer. However, because of the complex nature of fatigue testing of composites, these results cannot be viewed as conclusive for all materials and layups.<sup>[20]</sup>

#### **4.3.8. SUMMARY**

PMB paint stripping causes surface erosion in composites, unless the material is stripped only to the primer layer. Erosion of the gel coat (resin-rich surface) of the composite does not degrade mechanical properties, provided that severe damage to underlying fibers or matrix microcracking is not induced. Composites require less aggressive blast parameters than metals and strict, experienced operator control of the PMB process to prevent substrate damage.

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